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The evaluation and significance of intrapartum FHR-oscillation patterns

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1 Introduction

Fetal heart rate (FHR) variability is thought to be an important index of fetal health although it is well known that factors other than hypoxia and acidosis may deeply influence intrapartum FHR oscillation patterns. It is generally accepted that in the presence of normal variability the fetus is vigorous: lack of beat-to-beat fluctuation may be associated with fetal compromise. No general agreement exists about how to measure FHR variability. CALDEYRO-BARCIA [1] noted that the FHR-pattern consists of two phenomena: (1) very rapid fluctuations, socalled short-term irregularity or variation (STV); and (2) slow fluctuations, so-called long-term irregularity, seen as dips, decelerations and accelerations (LTV). STV denotes the real beat-to-beat changes between successive beats i.e. the R-R interval variability of the fetal ECG (FECG). It is impossible to quantitate STV of FHR records with accuracy in daily clinical routine. Therefore several approaches were made by different investigators: 1. computer analysis (mainly off-line) of FHR patterns yielding different variability-indices [2, 3, 10, 13] and 2. visual classification of oscillation patterns measuring the oscillation amplitude (OA) throughout different time periods [6, 9, 11]. The last method implies that the oscillation amplitude (OA) is closely related to the oscillation frequency (OF). The definition of OF is complex and not unanimously accepted. HAMMACHER [7] felt that one FHR-oscillation should be a whole sinus-wave i.e. the sequence of a visually detectable zenith and nadir of base-line FHR; this concept would lead to 5–8 cycles per minute in vigorous infants with normal beat-to-beat variability; this definition postulates that the zenith and the nadir alternate

Curriculum vitae

VOLKER MICHAEL ROEMER *was born in October 1940. At eighteen he began his studies at the Faculty of Medicine in the University of Freiburg i. Br. He continued in Paris (Sorbonne) and passed the final exams at Hamburg University. After first training in obstetrics and gynaecology at the University of Tübingen (1967–1969) he joint the staff of Prof.* KÄSER *at the University of Basel. 1974 he got his diploma as a specialist in obstetrics and gynaecology and was appointed university lecturer ("Privat-Dozent") in 1975. Since 1976 he is working at the department of obstetrics and gynaecology of the University of Tübingen (Chairman: Prof.* H. A. HIRSCH *and Prof.* K. HAMMACHER*). He specialized (two years) in biochemistry (University Hamburg, Prof.* KÜHNAU, *Prof.* HILZ*) and received a complete training in electronic data processing (IBM Switzerland). His main interest concerns perinatology.*

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in a comparable way to a sinus-wave; since this is not always encountered the parameter does not entirely reflect reality. Other investigators [5] counted the number of visually detactable peaks per minute in base-line FHR i.e. the turning-points from frequency acceleration to deceleration and vice versa in base-line FHR. This OF is closely associated with our clinical impression of FHR-variability but it is by no means equal to true STV; this OF amounts to 8–12 peaks per min, whereas STV is derived from 120–160 events (R-waves in the FECG) per minute. Recently HAMMACHER et al. [8, 12] pointed out that OF is an important predictor of neonatal condition at birth and subsequent infant survival: OF according to HAMMACHER below 2 per minute (i.e. 1 cycle per min which equals 2 oscillations in the present study) was associated with fetal acidosis and low APGAR score. It was the aim of this study to prove the validity of this concept from a clinical point of view.

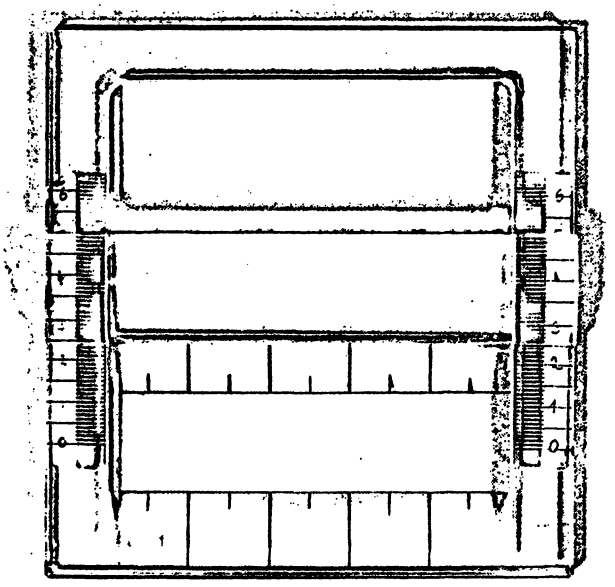

Fig. 1. A caliper specially made (plexiglas, 13 X 13 X 0.7 cm) to determine the oscillation amplitude in base line FHR. The accuracy was set to 1 millimeter which equals 2 bpm in our FHR records; visual rounding was performed. The distance between the regular markings is equal to one minute if a paper speed of 2 cm/minute is provided.

2 Material and methods

Computer are a useful tool for analysis of large amounts of data which are "hard", i.e. without mistakes. Erroneous data cause serious problems which are difficult to overcome by soft-ware configurations. The data stream composing instantaneous fetal heart frequency is usually contaminated with false signals throughout delivery; thus on-line computer analysis of FHR remains a delicate problem. We decided therefore to evaluate FHR patterns by visual analysis of records of high technical quality.

The last 120 minutes of 342 intrapartum tracings (41'040 min) were divided in 12 compartments each of 10 minutes duration and visually analysed with simple tools like compasses and caliper (Fig. 1). The following parameters were recorded: (1) The average base-line frequency per minute; (2) the oscillation amplitude (OA) of each minute i.e. the distance from the highest to the lowest point in base-line FHR (measured for convenience in millimeters by a specially made caliper); (3) the number of all visually detectable oscillation peaks per minute (Fig. 2); (4) the FHR-frequency (bpm) at the beginning, the lowest (highest) point and

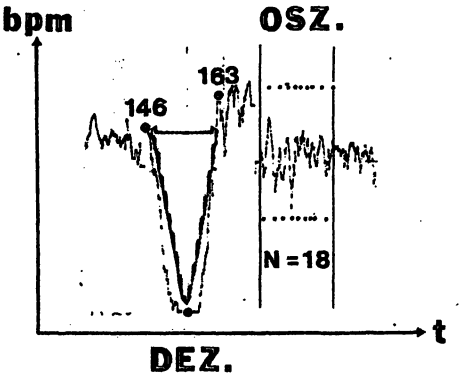

Fig. 2. The right part of the record shows how the oscillation frequency (OF) in base line FHR was evaluated: each visually detectable turning point (zenith and nadir) was counted; in this particular minute the sum amounted to 18 which is equal to 9 cycles according to HAMMACHER. There are minutes in which OF could only approximately be determined since the paper capacity becomes a limiting factor.

the end of each deceleration and each acceleration respectively; (5) the duration of each dip in mm (compasses) divided into two time periods: (a) distance from the beginning of the dip to its lowest point and (b) from there to the end of the

dip. Thus a + b comprises the whole duration of the deceleration; (6) each dip was classified qualitatively into 28 possible typs of deceleration (e.g. early deceleration, variable deceleration with "basal smoothness" etc); (7) finally the number of uterine contractions per 10 minutes. Thus all reasonable important phenomena of the FHR were recorded, encoded alphanumerically, entered on punched cards together with clinical and biochemical findings (25 cards/fetus), transformed into numerical values, carefully controlled by special computer-programs and stored on a file with direct access (IBM 370/135). The program system was developed by the author (Fortran). Only nonparametric statistics were applied. All FHR records were obtained by direct techniques where the R-wave of the FECG is used as trigger together with beat-to-beat processing of the electronic signal. The paper speed was 2 cm per minute. Records from fetuses with terminal caesarean section or long lasting and/or difficult vaginal operations were excluded due to the lack of signal continuity often encountered. Actual pH in cord blood was measured with Radiometer equipment (ABL II, BMS III, AME I). In two cases only APGAR-scores and no actual pH-values were available; thus the number of cases analysed in this context was 340.

3 Results

3.1 Non-acidotic fetuses

In the present study only the last 30 minutes (3 compartment per 10 min.) immediately preceding delivery were analysed with regard to OF and OA exclusively. Fetuses with an actual pH in the umbilical artery (UA) below 7.200 N = 87, 25.6%) were eliminated in order to exclude hypoxic FHR-variability disturbances. Records from 253 fetuses were left. From a total of 7590 (253 X 30) only 4615 (60.8%) minutes were free of any decelerations or accelerations. Fig. 3 gives the distributions of OF in these 4615 minutes; the mean OF was 9.5 ± 4.7; the variable is not normally distributed (KOLMOGOROV-SMIRNOV: $z = 5.34$, $2\alpha < 0.001$). The 5th percentile amounted to 2, the median to 9 and the 95th percentile to 18 oscillations per minute. Separation of the material according to the OA (Tab. I) yielded the data in Tab. I. The OF is closely related to the OA:

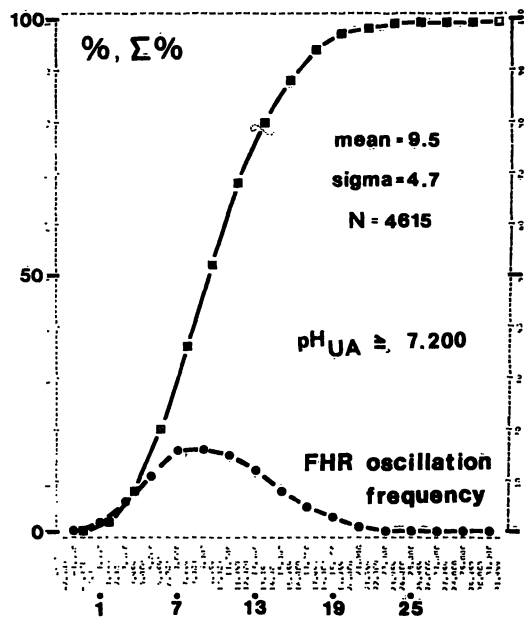

Fig. 3. Computer (IBM 370/135) print-out of percentage frequency distribution and percentage ogive of the oscillation frequency (OF) in 4615 base line FHR minutes of 253 fetuses with an actual pH in the umbilical artery above 7.199. Only the last 30 minutes preceding delivery were analysed. The variable is not normally distributed (KOLMOGOROV-SMIRNOV: $z = N^{1/2} \cdot D = 5{,}345$ where D = maximum $| F_0(X) - S_N(X) |$; $2\alpha < 0.01$ in 4'615 observations.

Tab. I.

Oscillation amplitude (bpm)	Minutes N	Minutes %	Oscillation frequency (N/min) $\bar{X}$	SD	5th Perc.,	50th Perc.,	95th Perc.
≥ 25	1487	32.2	11.1	4.3	4	11	19
24–10	2531	54.8	9.5	4.5	3	9	18
9–5	485	10.5	6.1	3.7	1	6	13
< 5	112	2.4	3.1	3.0	0	3	9

$\Sigma_{min} = 4615$, $pH_{UA} \geq 7.200$

reduction in oscillation frequency is associated with reduction in oscillation amplitude on a high level of significance; thus the mean OF in vigorous infants is decreased from 11.1 per minute with OA 25 bpm to 3.1 per minute with OA below 5 bpm. Fig. 4 shows a computer print-out of cumulative frequency distributions of the four variables under investigation. All distributions differ on a high level of significance from each other (KOLMOGOROV-SMIRNOV, $2\alpha < 0.001$); all four parameters are again not normally distributed ($2\alpha < 0.01$). It can be demonstrated, however, that in fetuses of mothers with no drug administration during delivery (N = 42) and with actual pH-values (UA) above 7.199 ($\bar{X}$ = 7.282, SD = 0.057) OF becomes normally distributed if the OA is not too great (10–5 bpm).

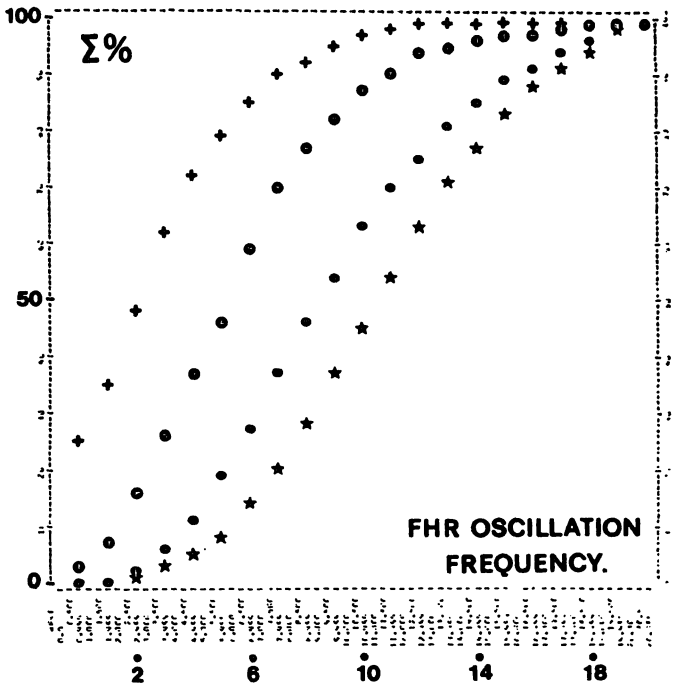

Fig. 4. Computer print-out of percentage ogives of the oscillation frequency (OF) in base line FHR minutes with four different oscillation amplitudes (OA): From the left to the right: < 5 bpm, 9–5 bpm, 24–10 bpm and ⩾ 25 bpm. All fetuses had an actual pH in the umbilical artery above 7.199; only the last 30 minutes preceding delivery were analysed. All four distributions differ from each other on a high level of significance (KOLMOGOROV-SMIRNOV: z between 5.6 and 3.4 where $z = ((N \cdot M) \cdot (N + M)^{-1})^{1/2} \cdot D$, and $D = \max | S_N(X) - S_M(X) |$; $2\alpha < 0.001$. For number of observations (i.e. minutes) see Tab. I. Note that increasing OF is associated with an increase in OA und vice versa even in vigorous infants.

3.2 Acidotic fetuses

From the results analyzed so far it is evident that, if we consider OF to be of clinical importance, we must always be aware of OA. Therefore if OF is a true predictor of fetal outcome OF should be diminished when compared with minutes of equal OA. 87 fetuses exhibited actual pH-values in the UA below 7.200 ($\bar{X}$ = 7.138, SD = 0.058). Similar computations led to the data in Tab. II: there is a trend to diminish OF in all four OA-groups. The decrease amounts to approximately 1 oscillation per minute; this difference is statistically not significant in all 4 distributions (KOLMOGOROV-SMIRNOV). If the actual pH is further lowered below 7.151 ($\bar{X}$ = 7.099, SD = 0.047, N = 44) the data in Tab. III are obtained: The median of each of the four distributions is decreased again; the differences are statistically significant* when compared in a similar manner with OF-distributions of fetuses with 7.150 < actual pH < 7.250 except

* ⩾ 25 bpm: 2α = n.s., 24–10 bpm: 2α = 0.00185, 9–5 bpm: 2α = 0.0912, < 5 bpm: 2α = 0.0358, all data together: 2α = 0.000066 (KOLMOGOROV-SMIRNOV)

Tab. II.

Oscillation amplitude (bpm)	Minutes N	Minutes %	Oscillation frequency (N/min) $\bar{X}$	SD	5th Perc.,	50th Perc.,	95th Perc.
⩾ 25	464	35.6	11.0	3.8	5	11	17
24–10	631	48.5	8.6	4.3	3	8	16
9–5	165	12.7	5.0	3.4	0	5	11
< 5	41	3.1	1.5	2.1	0	0.5	5.5

Σ_{min} = 1301, $pH_{UA} < 7.200$

Tab. III.

Oscillation amplitude (bpm)	Minutes N	Minutes %	Oscillation frequency (N/min) $\bar{X}$	SD	5th Perc.,	50th Perc.,	95th Perc.
⩾ 25	239	37.6	10.9	3.9	4	11	17
24–10	292	45.9	8.4	4.3	2	8	16
9–5	83	13.0	4.9	3.6	0	4	11
< 5	21	3.3	0.9	1.4	0	0	3.5

$\Sigma_{min} = 635$, $pH_{UA} < 7.150$

for the OF-distribution with OA ⩾ 25 bpm. There is a trend to increase the differences of the four median-values in the two populations with decreasing OA (see Tabs. I and III): The difference amounts to 0 in the group with OA ⩾ 25 bpm, to 1 (OA: 24–10 bpm), to 2 (OA: 9–5 bpm) and to 3 (OA: < 5 bpm). Analogous computations with the one and five minute Apgar-score were not performed since the Apgar-score does not seem sensitive enough to rule out such delicate problems.

4 Comments

The present method of evaluation of FHR-patterns seems to be unacceptable when compared with on-line or off-line computer analysis. Nevertheless this method yields the utmost precision we can achieve in clinical fields without electronic devices used for data acquisition. In our opinion and according to our own experience with off-line computer analysis of FHR this method even offers several advantages: (1) One can be sure that data entered in the computer make sense; "garbage in, garbage out" is at least one part of the problem of electronic analysis. This holds especially in detecting and classifying decelerations and accelerations. On the other hand there will be no doubt that OF can be only approximately determined in minutes with small OA (e.g. < 5 bpm) since the registration capacity of the paper becomes a limiting factor.

(2) This method of evaluation is closely related to what we perform in daily clinical routine observing intrapartum FHR records; thus the results analyzed so far are more comprehensive than any FHR variability-index and may be helpful too in clinical management of high risk fetuses.

The figures indicate that we must be careful in the diagnosis of fetal distress in cases with reduced FHR variability if no other signs of jeopardization are present (e.g. late decelerations, marked variable decelerations). The very heart of the problem seems to be the fact that loss of beat-to-beat variation measured in terms of OF is a common phenomenon even in vigorous fetuses and might be due to quiet sleep state [4] and maternal drug administration. Reduction of beat-to-beat fluctuation due to hypoxia may be superimposed and therefore difficult to quantitate clinically. The obstetrican will not be able to quantify such complex conditions by just looking at the record, especially if the OA is above 10 bpm. However if OA in baseline FHR (without other symptoms) is below 5 bpm and there is a "wiggling" on the FHR record one might be sure that there is still time enough to perform microblood sampling in order to determine the true fetal condition. This statement holds only if strict beat-to-beat processing of the electronic signal as well as an accurate peak detection of the R-wave of the FECG is provided. On the other if FHR varies less than 5 bpm and beat-to-beat irregularities are completly missing, and if gentle manipulation of the fetus does not evoke variability, one should be prepared to meet significant fetal acidosis. These statements are merely clinical rules supported by the findings presented in this study.

A good diagnostic connotation has been ascribed to FHR variability, but the observation of its absence – smoothness – requires additional comment: Factors other than fetal asphyxia may be involved, which include immaturity, fetal inactivity or "quite sleep" as well as maternal drug administration. Whenever FHR smoothness is noted an

explanation of its probable origin should be sought. If ominous deceleration patterns are present the clinical management will be governed by the total of information of the FHR record and thus become a reliable predictor of the true fetal outcome.

Summary

The last two hours of 342 intrapartum FHR records of high technical quality were evaluated visually with simple tools (compasses, caliper). All data were entered on punched cards (25 pro fetus) and analyzed using an IBM system 370/135. In 253 fetuses with an actual pH in the umbilical artery (UA) above 7.199 the oscillation frequency (OF) during the last 30 min. preceding delivery amounted to 9.5 ± 4.5 (4615 minutes without decelerations or accelerations). The 5th percentile, the median and the 95th percentile were 2,9 and 18 per minute respectively. OF refers to the number of visually detectable turning points in baseline FHR. There exists a significant association ($2\alpha < 0.001$) between the OF and the oscillation amplitude (OA) per minute: a reduction in OF is followed by a decrease in OA even in vigorous infants. In acidotic fetuses OF is decreased when compared with FHR minutes of equal OA in nonacidotic infants. However this becomes statistically significant only in fetuses with actual pH (UA) below 7.150 i.e. in fetuses with severe acidosis. **These findings can explain why the loss of FHR variability as a single symptom may be misleading in individual cases.**

Keywords: Basal frequency level, computeranalysis, CTG intrapartale, expulsion period, fetal acidosis, oszillation frequency.

Zusammenfassung

Auswertung und Bedeutung der FHR-Oszillationsfrequenz unter der Geburt

Die beiden letzten Stunden von 342 intrapartalen, technisch möglichst einwandfreien Cardiotokogrammen wurden manuell, mit einfachen Hilfsmitteln (Stechzirkel, Schublehre) ausgewertet. Die Papiervorschubgeschwindigkeit betrug 2 cm pro Minute. Es wurden Geräte der Firma HEWLETT-PACKARD verwendet. Alle Daten wurden auf Lochkarten (25 pro Fetus) übertragen, abgelocht und auf einem IBM-System 370/135 weiter verarbeitet. Registriert wurde die mittlere basale Frequenz pro Minute, die Bandbreite, die Oszillationsfrequenz sowie wesentliche Daten aller Oszillationen und Akzelerationen. Die Oszillationsfrequenz wurde durch Auszählen der mit dem Auge erkennbaren Hoch- und Tiefpunkte der basalen fetalen Herzfrequenz pro Minute bestimmt.

Bei 253 Feten mit einem aktuellen pH in der Nabelarterie über 7.199 betrug die Oszillationsfrequenz während der letzten 30 Minuten vor der Geburt 9.5 ± 4.5 bei 4615 ausgewerteten CTG-Minuten. Die 5. Percentile lag bei 2, die 50. Percentile bei 9 und die 95. Percentile bei 18 peaks pro Minute. Es fand sich eine hochsignifikante Abhängigkeit ($2\alpha < 0.001$, KOLMOGOROV–SMIRNOV) zwischen der Oszillationsfrequenz und der Oszillationsamplitude pro Minute: Mit Rückgang der Oszillationsamplitude kommt es immer auch zu einem Rückgang der Oszillationsfrequenz. Dies gilt auch für Feten mit guten pH-Werten. Bei fetaler Azidose nimmt die Oszillationsfrequenz pro Minute in CTG-Minuten mit vergleichbarer Bandbreite weiterhin ab (Tab. II). Dieser Oszillationsfrequenzrückgang wird jedoch erst unterhalb eines pH in der Nabelarterie von 7.150 statistisch faßbar (Tab. III). **Die Daten belegen die klinische Erfahrung, daß Oszillationsamplitude und Oszillationsfrequenz stramm miteinander korreliert sind und demnach auch gemeinsam beurteilt werden müssen.** Sie zeigen weiterhin, daß ein deutlicher Rückgang der Oszillationsfrequenz Zeichen einer bereits manifesten fetalen Azidose ist.

Schlüsselwörter: Austreibungsperiode, Computeranalyse, fetale Azidose, intrapartales CTG, Oszillationsamplitude, Oszillationsfrequenz.

Résumé

Evaluation et signification des modèles d'oscillation de la FCF intrapartum

Les deux dernières heures de 342 cardiotocogrammes (CTG) intrapartum d'une précision technique maximale ont été évaluées manuellement par des moyens simples (compas à pointes sèches, pied à coulisse). La rapidité d'avancement de la bande a atteint 2 cm/min. On a utilisé des appareils de la firme HEWLETT-PACKARD. Toutes les données ont été transmises sur cartes statistiques (25 par foetus), perforées et retraitées sur un système IBM 370/135. Ont été enregistrées la fréquence basale moyenne/min., l'amplitude, la fréquence d'oscillation (FO) ainsi que les données essentielles de toutes les décélérations et accélérations.

Chez 253 foetus avec un pH actuel dans l'artère ombilicale supérieur à 7,199, la fréquence d'oscillation a atteint 9,5 ± 4,5, N = 4615 pendant les 30 min. précédant la naissance. Le 5ème percentile s'est situé à 2, le 50ème percentile à 9 et le 95ème à 18 «évènements»/min. Sur l'amplitude située entre 120 et 160 battements/min., on observe pendant les 30 dernières min. antepartum une dépendance très significative entre, d'une part, la fréquence: Plus la FCF basale est élevée, plus le nombre des oscillations décelables/min. est réduit. La baisse de la fréquence

d'oscillation est linéaire et correspond à environ 1 «évènement» pour 10 battements/min. En cas d'acidose foetale, la fréquence d'oscillation continue de baisser indépendamment du niveau de fréquence basale.
Ce recul de fréquence d'oscillation ne peut être statistiquement fixé que chez les foetus avec un pH actuel dans l'artère ombilicale inférieur à 7,150. Les données permettent d'établir que l'obstétricien devrait toujours tenir compte du niveau de fréquence dans l'évaluation clinique de la fréquence d'oscillation de la FCF basale. **La baisse de fluctuation de la FCF ne représente pas, dans les cas particuliers, un signe certain d'une hypoxie foetale.**

Mots-clés: Acidose foetale, analyse d'ordinateur, CTG intrapartum, fréquence d'oscillation, niveau de fréquence basale, période d'expulsion.

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